SEDIMENTOLOGICAL FACTORS AFFECTING THE DISTRIBUTION AND GROWTH OF VISÉAN CANINIOID CORALS IN NORTH-WEST IRELAND

by J. A. E. B. HUBBARD

ABSTRACT. The Viséan limestone-shale sequences of north-west Ireland contain a characteristic distribution pattern of alternating coraliferous and 'barren strata' (called 'inter-beds'). The varied geniculation in the assemblages of prone solitary caninioids in both types of strata are interpreted from comparison with observations and experiments on modern corals, as showing a close relationship of coral growth to stability, sedimentation, and penecontemporaneous erosion of the soft lime-mud substrate. Two types of lime-mud are found in the axial region of the corals: fine homogeneous micrite flooring the tabulae is regarded as original infill, while extraneous biomicrite, introduced through openings caused by penecontemporaneous erosion and boring sponges and bryozoa is evidently of subsequent origin. Adverse environmental conditions during skeletogenesis are believed to be responsible for the widely spaced tabulae, conspicuously thin skeleton, and suppression of the dissepimentarium, which are irregularly developed and often associated. The effects of compactional loading and diagenesis are outlined. Each bedding-plane strewn with adult caninioids is regarded as a winnowed death assemblage involving many different generations and accumulating during periods of slow deposition. The difficulties for corals living on an unlithified sea bed are discussed and some wider regional implications considered.

BEDDING-PLANES strewn with large solitary cylindrical Rugose corals (Pl. 41, fig. 1) alternating with comparatively barren strata are common in the Viséan limestone–shale sequences of north-west Ireland. The coralliferous partings are particularly well known from around the shores of Donegal Bay from whence they have been described since the mid nineteenth century (see Wynne 1864, p. 38; Wynne 1885). Until now no ecological interpretation has been attempted, but this would now seem opportune in the light of recent work on ancient and modern carbonate sedimentology and on modern coral habits.

METHOD

Detailed field observations form the bulk of this work because little of the material is suitable for laboratory study. The Viséan around Donegal Bay from Easky (Irish National Grid Reference G380 385) to Muckros Head (I.N.G.R. G620 375) (see text-fig. 1) is ideally exposed in sections showing deeply weathered, almost horizontal strata. But crucial information has been derived from the comparatively poorly weathered inland escarpments of Benbulben (I.N.G.R. G684 462) and Knocknarea (I.N.G.R. G622 350). Quantitative field analyses which involved more than 3000 caninioids include data incorporated in the 100 one-metre quadrat analysis (see Hubbard 1966, p. 254) of the following localities: Easky (I.N.G.R. G380 385), Aughris (I.N.G.R. G485 350), Serpent Rock (I.N.G.R. G558 460), and Streedagh Point (I.N.G.R. G627 510). Selective laboratory studies which exposed the three-dimensional relationship of the coralla to their matrices and infilling material were implemented by means of polished and etched specimens, thin sections, and acetate peels. In addition 160 thin

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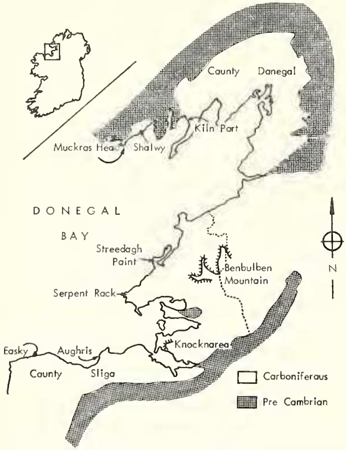
sections and 320 acetate peels of the associated sediments at Streedagh Point and Easky were studied petrographically.

Terminologically the caninioids mentioned include the solitary specimens of *Caninia* spp. and *Siphonophyllia* spp. listed in stratigraphical accounts of the area (see Table 1). Systematic studies show that there is much intraspecific variation at Streedagh Point (Dixon 1970) but all those corals quoted are siphonophyllids, whereas outside this locality occasional caniniids are known notably in Co. Donegal.



TEXT-FIG. 1. Outline map of the Sligo–Donegal coast to show the location of the most informative sections in the Viséan limestone–shale sequences in relation to their regional setting.

EVIDENCE

1. *General distribution.*

Corals occur throughout the limestone–shale sequences of north-west Ireland but are remarkably rich on certain bedding-planes. There is a tendency for one member of the fauna to predominate in each stratum, e.g. caninioid, zaphrentoid, fasciculate, or cerioid lithostrotionoid corals. But of these the caninioids are not only the most spectacular in the variability of their growth forms and distribution patterns, but are also the most ubiquitous in their sedimentary associations. They are found in biosparites and shales as well as all intermediate sediment types. Their distribution, which may be compared with other faunal elements, mirrors subtle lithological variations. Essentially their occurrence can be divided into two categories which have distinct sedimentological associations, (*a*) caninioid-dominated bedding-planes and (*b*) interbeds with sparse caninioids (see Table 2); the main difference being that whereas the former accumulates almost invariably represent condensed composite death assemblages

EXPLANATION OF PLATE 41

Fig. 1. An adult caninioid-dominated bedding-plane at Serpent Rock showing the comparatively uniform size and variability in growth forms of the partially silicified, randomly oriented, prone coralla of a composite winnowed death assemblage. The deep weathering of the present day intertidal zone has eroded the majority of the epithecae thus exposing many internal structures in longitudinal section. The corals rest on a crinoidal biomicrite, which probably equates with a high energy organic sand substrate, but are overlain by an impure dark trace fossil-riddled micrite matrix, which represents a lower energy rapidly deposited lime-mud. Scale of 1000 mm.

Fig. 2. A vertical polished section of a prone adult caninioid from a block of graded biomicrite at Streedagh Point showing extensive penecontemporaneous erosion of the upward facing surface of the coral. The caninioid's lower surface rests on a more richly organodetrital biomicrite of coral–echinoderm–brozoan debris than the overlying material which has a somewhat higher mud content. Scale of 50 mm.

1

2

HUBBARD, Caninioid corals

the latter occasionally incorporate individuals which are thought to be preserved in positions of growth.

(*a*) *Caninioid-dominated bedding-planes*. The bedding-planes strewn with large adult prone caninioids (Pl. 41, fig. 1) are particularly conspicuous in the shore sections of Streedagh Point, Serpent Rock, Aughris, and Easky. This style of exposure usually results from differential weathering of weak partings at limestone–shale interfaces. Thus, where thin shale partings overly the corals the overlying limestone is readily

TABLE 1. The regional distribution and systematic status of the caninioids discussed according to the stratigraphical lists in 1, Oswald (1955), 2, Bowes (1957, unpublished Ph.D. thesis University of Glasgow), and 3, George and Oswald (1957).

	Co. Sligo			*Co. Donegal*	
Systematic status	*Benbulben*	*Aughris*	*Easky*	*West*	*South-east*
Caninia cornucopiae Michelin	1				3
C. benburbensis Lewis		2	2		
C. cf. *benburbensis* Lewis		2	2		
C. cf. *cylindrica* (Scouler)	1	2	2		
Caninia sp.		2	2		
amplexoii caniniids				3	
Siphonophillia cylindrica (Scouler)				3	
S. cf. *cylindrica* (Scouler)				3	
S. cf. *britoliensis* (Vaughan)				3	
S. cf. *benburbensis* (Lewis)				3	
Siphonophyllia sp. (see Lewis 1927, p. 37)					3

undermined and stripped off. The partially silicified coralla resting in or on the underlying silty biomicrites are thus left as upstanding features in the contemporary foreshore. Where the overlying shale parting is absent or limited to an unusually thin veneer the corals do not weather out so readily on the surface of bedding-planes, but are traceable in bands along the cliff. The true lateral extent of these caninioid-dominated planes is difficult to determine. Inland they give the impression of continuity over a matter of kilometres, but coast sections expose much small-scale faulting which complicates correlation. Certainly the evidence available suggests that the minimum continuity is in excess of 30 m. The distribution of caninioids within these planes is more variable and their orientation is apparently random (compare text-figs. 2 and 3). Caninioid population densities vary from four to eleven adults per square metre. Occasionally such concentrated accumulates pass abruptly into 'barren' areas within a metre, and in these cases there is usually evidence of shoaling organic debris on the lee sides of the caninioids.

There is a marked tendency for a uniformity of late neanic growth stages to predominate. These range up to 1064 mm. in length and 82 mm. in diameter, but average 505 mm. in length and 76 mm. in diameter. Juveniles are rare or absent. Growth forms, however, are highly variable and random in their associations. Thus straight, gently arcuate, and complexly geniculate forms often occur together. Though the proportion of straight to geniculate caninioids is not constant, the latter tend to be more numerous (text-fig. 4*a*). There is no correlation between the size of the corallum, the number, type, or distribution of geniculations. Thus geniculate caninioids range from simply curved

TABLE 2. A synoptic comparison of the caninioid-dominated strata and 'inter-beds' to show their contrasts in population structure, population density, epifauna, thickness, and lithological associations.

	Caninioid-dominated bedding-planes	*'Inter-beds'*
1. *Approximate frequency of 'inter-beds' to caninioid-dominated units*	1 in 16.	16 to 1.
2. *Average thickness of unit*	Variable—less than 50 mm.	100–9015 mm.
3. *Population structure*		
(*a*) *Density*	High (up to 11 adults per sq. m.).	Low.
(*b*) *Frequency*	Constant.	Sporadic.
4. *Growth stages present*	Mainly adults (*c.* > 90%).	Juveniles dominant, most growth-stages known.
5. *Growth forms recorded*	All styles from complexly geniculate in several planes to simple straight forms.	Straight or simple forms with only small simple geniculations at the apical end.
6. *Orientation*	90% prone (i.e. long axis of the corallum parallel to bedding). 10% low angle oblique to bedding.	80% prone (mainly adults). 10% inverted (mainly ephebic and young neanic). 7% in position of growth associated with fasciculate lithostrotionids (all growth stages except gerontic). 3% independently in position of growth (usually young neanic).
7. *Evidence of attachment*		
(*a*) *Scars*	None.	None.
(*b*) *Holdfasts*	Three neanic individuals attached to one adult specimen at Serpent Rock (text-fig. 5 3).	Rare: (*a*) young neanic individual attached to a spiriferid fragment by rootlets at Serpent Rock (*b*) one adult attached to linoproductid fragment in the Streedagh Shales at Streedagh Point.
8. *Epifauna*	Rare: a local feature at Easky and Pound Point (St. John's Point).	Rare.
(*a*) *Aulopora*	Encrusting upward facing surfaces of prone caninioids, linoproductoids, and davisielloids.	Encircling the median region of one upstanding juvenile caninioid in position of growth at Largymore.
(*b*) *Boring by sponges and bryozoa*	Both types known. Penetration restricted to theca. Locally common, e.g. Streedagh Point, Easky.	Not recorded.

9. *Damage*	Sporadic epithecal erosion in some adults.	Limited to prone adults.
10. *Associated fauna*	Variable in numbers and kinds: generally not forming a significant proportion of the population. Chiefly corals, long hinged brachiopods and bryozoa, with crinoid and trilobite debris.	Variable in numbers and kinds: often forming a significant proportion of the population: generally mixed with dominance of corals and brachiopods (including short hinged forms).
(*a*) *Nos. of families and genera*	Restricted.	Diverse.
(*b*) *Nos. of individuals*	Comparatively 'high'.	Sparse.
(*c*) *Sizes and growth stages*	Uniform.	Not conspicuously uniform.
(*d*) *Preservation*	Generally transported and commonly disarticulated.	Mixed autochthonous and indigenous.
(*e*) *Commensal*	None.	Fasciculate lithostrotionids.
11. *Associated sediment*	Variable often with impurities.	Generally uniform.
(*a*) *Overlying the corals*	(*a*) Commonly dark shales and shaly biomicrites passing up into biomicrites.	
(*b*) *Underlying the corals*	(*b*) Occasionally uniform biomicrites. Commonly biomicrite: composition variable, usually light-coloured biomicrite, occasionally darker and gradational towards shelly micrite.	Uniform, either (*a*) light-coloured barren micrite, (*b*) light-coloured crinoidal biomicrite, or (*c*) shales.
12. *Interpretation*	Almost invariably composite death assemblages.	(*a*) *Mainly transported death assemblages.* (*b*) Occasional individuals in position of growth, e.g. Serpent Rock, Streedagh Point, Knocknarea, and Largymore.

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9. *Damage*	Sporadic epithecal erosion in some adults.	Limited to prone adults.
10. *Associated fauna*	Variable in numbers and kinds: generally not forming a significant proportion of the population. Chiefly corals, long hinged brachiopods and bryozoa, with crinoid and trilobite debris.	Variable in numbers and kinds: often forming a significant proportion of the population: generally mixed with dominance of corals and brachiopods (including short hinged forms).
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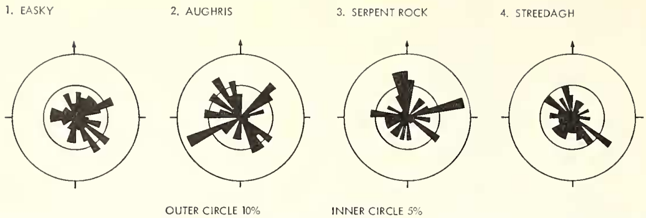
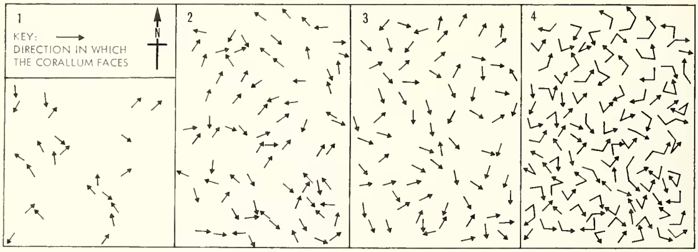


TEXT-FIG. 2. Rose diagrams to illustrate the random orientation of the geniculate caninioids in the caninioid-dominated bedding-planes. Each diagram represents 100 readings in which the angle of interception of the coral is plotted.



TEXT-FIG. 3. Diagrammatic illustration of an analysis of the orientation of 100 prone, adult caninioids on a single bedding-plane at the top of the Streedagh Point succession. Inset 4 represents the field evidence, in which all stages of the coral growth visible are plotted. The directions in which arrows point indicate the orientation of the calices and their geniculations are plotted to the nearest degree. The diameters of the coralla are constant but unrepresented. The relative lengths of the intergenicular regions are approximately in proportion. Inset 3 represents the final stage of growth only. Inset 2 shows the orientation of the coralla before the last geniculation, while inset 1 records only the first stage of growth visible. Thus there seems to be no apparent preferred orientation either at a particular growth stage or *in toto*.

cylindrical specimens to more complex S– and Z–shapes in which the geniculation(s) occur in one plane or at random. Similarly the genicular angle may be wide and gently arcuate or narrow and sharply V-shaped. Geniculations show no constant relation to the situation of the cardinal quadrant, apex, or calice. The epitheca is often partially removed from the upper surface of the corals as a result of penecontemporaneous

EXPLANATION OF PLATE 42

Close-up of a prone caninioid in a naturally eroded, longitudinal section resting in a bioturbated coralliferous biomicrite at Serpent Rock. This illustrates the fine detail often visible in the field as compared with laboratory preparations (Pl. 44). The corallum shows repetitive suppressions of the dissepimentarium, local asymmetrical development of the dissepimentarium, local thinning of the septa (halfway up the coral), and a gently arcuate geniculation suggesting that this coral's life was periodically fraught with the dangers of silting up during adverse conditions. Scale of 100 mm.

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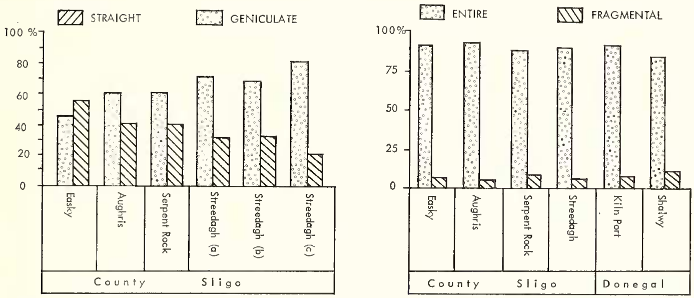
erosion (Pl. 41, fig. 2), but this damage is seldom extensive and breakages are few numbering less than 10% of any population studied (Text-fig. 4*b*).

(*b*) '*Inter-beds*'. In contrast to the caninioid-dominated strata these are varied in thickness, lithology, and faunal content (Table 2). They contain few whole fossils but are composed of a high organo-detrital content. The population is low in numbers but more varied, containing representatives of various growth stages of a fauna which appears to be



TEXT-FIG. 4. Caninioid statistics: Left, histogram to show the ratio of geniculate to straight caninioids within a single bedding-plane. Three horizons are cited at Streedagh Point. A dominance of geniculate forms is generally discernible. Right, percentage histogram of entire and fragmental caninioids calculated from 100 one-metre quadrats at each locality.

locally indigenous and occasionally in position of growth (Text-fig. 5). Whereas the caninioid-dominated bedding-planes are generally marked by an abrupt change in sedimentary style, e.g. silty biomicrite to bioturbated shale, the 'inter-beds' are conspicuous for their uniformity. At most they are graded within the individual stratum. But there is a tendency for these 'inter-beds' to be terminated abruptly at their upper surface by a caninioid-dominated bedding-plane.

2. *Caninioid growth*

Longitudinal axial sections exposing the tabularium, many of which are as well etched in the field (Pl. 43) as can be achieved in the laboratory (Pl. 44), are plentiful in the foreshores and yield important information on the growth of the corallum. The arrangement of the tabulae, though variable in detail, is generally parallel to the orientation of the external growth rings. This constancy may be used indirectly as evidence of the probable direction of growth of the live coral.

(*a*) *Geniculation*. A gradual compensational swing of both tabulae and growth rings is usual (Text-figs. 5 1, 2; Pl. 43). Abrupt changes are rare.

(*b*) *Attachment*. Evidence is seldom found as the apical region is either buried or rarely seen preserved. Three juveniles are known on the epitheca of one adult caninioid

(Text-fig. 5 3), while another juvenile attached itself to a spiriferid fragment by supporting 'rootlets'. Only one attached adult is known from Co. Sligo; it is cemented apically to a linoproductid fragment in the basal shales of Streedagh Point. In all four cases the scar is evident, but small. No evidence of attachment scars is found outside the apical region.

(*c*) *Attitude of growth*. Several young caninioids are known in upright positions which would seem to be functionally viable (Text-figs. 5 1, 2, 3; Pl. 44, fig. 1). These are recorded from 'inter-beds' and are known from similar sediments in the escarpments of Knocknarea and Benbulben as well as the shores of Easky, Aughris, Serpent Rock, Streedagh Point, and Shalwy. But they are rare occurrences limited to homogeneous biomicrite and silty biomicrite facies. Several neanic and ephebic caninioids are found in this position where they are intergrown with fasciculate lithostrotionoids as though deriving benefit from their shelter (Pl. 44, fig. 1).

3. *Preservation*.

(*a*) *Axial infill*. The advanced state of diagenesis of both corallum and matrix often obscures the original nature of the axial infill. The coralla are preserved in finely crystalline silica and carbonate, from which, by granular cementation of the carbonate crystals, the intraskeletal voids are filled. Locally coarse drusy carbonate is developed, often at the expense of the skeletal structure. Thus tabulae, septa, and dissepiments terminate abruptly against the mosaic (Pl. 43). The coarse mosaic is commonly developed in bands of less than 50 mm. deep within the tabularium. Occasionally this extends laterally into the dissepimentarium.

In addition to the crystalline infill, lime-mud is found locally in the axial region. This consists of two types, (*a*) very fine homogeneous micrite flooring the tabulae, and (*b*) extraneous silty biomicrite which frequently completely fills the intertabular space but shows no geopetal features. This latter infill often occurs in the genicular region of the corallum, where the skeleton is conspicuously thin, and/or in areas where the tabulae are disorganized.

(*b*) *Penecontemporaneous erosion*. Caninioids are seldom as extensively eroded as the one illustrated in Plate 42, but localized erosion of parts of the corals' outer surface is not uncommon. Damage is usually restricted to the upward facing sector of the corallum. Often the epitheca is breached, but penetration is known to extend as far as the tabularium thus allowing the introduction of extraneous lime-mud into the axial region. This type of damage is readily distinguished from the products of differential loading and diagenesis (compare Tables 3 and 4).

EXPLANATION OF PLATE 43

A longitudinal section of a deeply etched, prone, geniculate caninioid. The dissepimentarium shows pronounced constrictions on the convex side and a certain degree of asymmetry. The tabular region is locally confused by diagenetic rupture, while the intertabular interval is somewhat masked by the uneven distribution of carbonate mosaic and silica. Scale of 10 mm.

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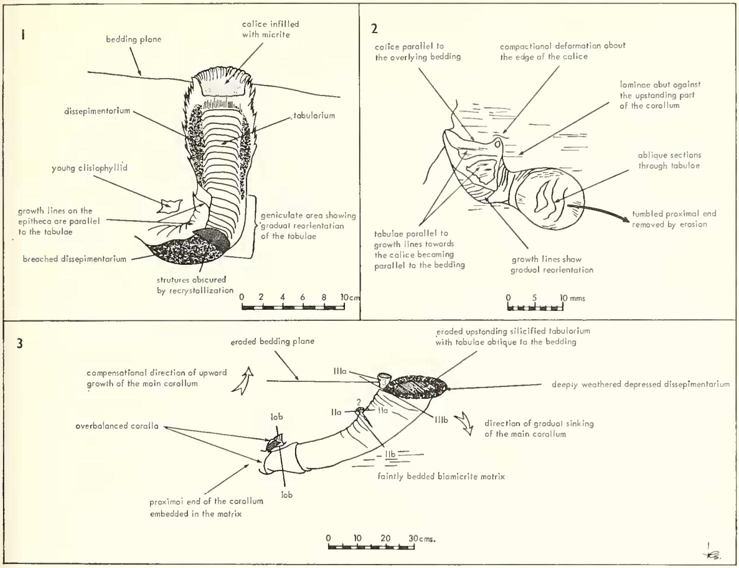

TEXT-FIG. 5. Caninioid corals preserved in their probable positions of growth.

(1) Field sketch of an adult geniculate caninioid at Serpent Rock illustrating the relationship of the calice to the axial structures and bedding. There is a conspicuous parallelism of growth-lines, tabulae, and calice, which distally are almost parallel to the bedding. The apical region is inaccessibly buried in the matrix. The geniculate development of the corallum suggests that the young coral became unbalanced and managed to reorient itself successfully with respect to its substrate by gradual upright growth, which is reflected in both growth rings and tabulae.

(2) Sketch from a peel of a young geniculate caninioid from Knocknarea illustrating the relationship between the corallum and matrix. In the upstanding portion of the corallum the bedding terminates abruptly against the epitheca indicating that deposition and coral growth were contemporaneous. The calice is at a low angle, in this case almost parallel to the succeeding sedimentary laminae. The growth history of the coral may be traced from the orientations of the tabulae and growth-lines with respect to the bedding. During its early life the coral overbalanced and came to rest obliquely on the sea bed, but compensation reorientation enabled the polyp to resume its upright position and continue growing until its premature death. This probably resulted from 'suffocation' as there seems to be little evidence of a break in sedimentation between the coral's successful readjustment and its final burial. At the calical margin the overlying bedding, which is affected by compactional deformation, and is of post-mortem origin completely transgresses the corallum.

(3) Field sketch of a caninioid life assemblage comprising an adult supporting three juveniles at Serpent Rock. The inferred directions of settling of the main corallum are indicated by the angular discordance between its growth rings (Ib, IIb, IIIc) and those of the small coralla (Ia, IIa, IIIa) which probably initially attached themselves in an erect position.

TABLE 3. A synopsis of caninioid features which result from post-mortem causes.

Feature	*Area affected*	*Frequency*	*Cause*
SKELETAL DAMAGE			
1. Thecal breaching; occasionally superficial sometimes associated with damage of contiguous internal structures, e.g. abruptly truncated tabulae (see Pl. 41, fig. 2).	Commonly confined to upper surfaces of prone adults. Locally coincident with geniculations.	Irregular.	Contemporaneous erosion while strewn over the sea bed.
2. Tabular slivers arranged *en échelon* between complete tabulae.	Random.	Irregular.	Expansional rupture during diagenesis.
3. Tabulae missing and/or represented by slivers with random orientation in biomicrite filled intertabular area.	Random. Sometimes associated with particularly thin skeletal areas.	Irregular.	Introduction of extraneous material resulting from local breaching by contemporaneous erosion.
4. Planar orientation of skeletal fragments parallel to the bedding.	Variable, often extensive or developed throughout the length of the corallum.	Common.	Crushing during compactional loading.
INFILLING MEDIUM			
1. Homogeneous micrite A.	Locally developed flooring intertabular areas.	Rare.	Original.
2. Homogeneous micrite B.	Local, usually associated with the external margin of the dissepimentarium.	Sporadic.	Diagenesis.
3. Drusy carbonate.	Local, commonly restricted to 50 mm. thick bands in the tabularium, but is also found affecting adjacent areas of the tabularium.	Sporadic (total loss of internal structures).	Diagenesis.
4. Cryptocrystalline silica.	Locally present in intertabular area.	Sporadic.	Diagenesis.
PRESERVATION OF CORALLUM			
1. Microcrystalline carbonate.	Throughout.	Usual.	Replacement.
2. Cryptocrystalline silica.	Irregular, usually best developed at the theca, from which it selectively penetrates the septa.	Variable.	Permineralization.

TABLE 4. A synopsis of caninioid features which result from the contemporaneous effects of mobile sediment on the growing corallum.

Feature	*Effects or areas affected*	*Location*	*Frequency*	*Likely cause*
GENICULATION	(*a*) External form (*b*) Tabularium (*c*) Dissepimentarium.	Random.	Irregular but common.	Negative geotropic readjustment resulting from (*a*) Instability on substrate, (*b*) Unfavourable original attachment, (*c*) Directional growth away from sediment.
TABULARIUM				
1. Intertabular distance.	(*a*) Tabulae locally crowded.	Random.	Irregular, usually limited.	Favourable conditions, with sufficient carbonate for additional growth.
	(*b*) Tabulae locally widely separated, often coincident with particularly thin tabulae and restricted dissepimentarium.	Random.	Irregular.	Adverse conditions: (*a*) Lack of carbonate for skeletal growth, (*b*) Need of rapid upward extension of the skeleton to avoid choking by mobile sediment.
2. Orientation of tabulae.	(*a*) Oblique to previous tabulae. (*b*) Off-lapping. (*c*) Overlapping. Often associated with parallel directional change in external growth rings.	Variable, most common in genicular areas.	Common.	Compensational growth resulting from readjustment of growth direction.
3. Broken tabulae.	Concentric arrangement of tabulae occupying one intertabular space. Usually associated with thin tabulae.	Irregular.	Rare.	? contemporaneous collapse of calice during adverse conditions.
DISSEPIMENTARIUM				
1. Crowding of dissepiments on concave side of geniculation.	Local, coincident with geniculations.	Variable.	Irregular.	Response to concentric growth about a curve.
2. Locally suppressed: (*a*) symmetrically, (*b*) asymmetrically.	Associated with thin distantly spaced tabulae.	Variable.	Irregular.	Adverse conditions: (*a*) Lack of carbonate for skeletal growth, (*b*) Need added height rather than sturdiness.